Indian J Phys. 82 (10) 1255-1263 (2008)

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SEPs associated CMEs affecting near earth environment

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Received 20 December 2007, accepted 31 July 2008

Abstract : The geoeffectiveness of seventy-five Solar Energetic Particles (SEPs) effective coronal mass ejection (CMEs) have been investigated during the period 1997-2005. The seventy-five events have been classified into different groups according to proton intensity and their geospatial response have been examined. The geomagnetic storms are measured with the minimum Dst value occurring within a day or first half of next day after the SEP maximum during the event It is observed that higher SEP intensity is better correlated with Dst than the lower proton intensity, so that, higher SEP intensity leads to intense geomagnetic storms (GMSs), and, lower proton intensity to moderate GMSs. It is observed that there is no significant correlation between proton intensity and flare size in terms of X- ray peak flux The source location is also one of the important parameters in deciding the geoeffectiveness of SEP effective CMEs *i e*, the nature of GMSs. It is further observed that 2001 and 2003 are most peculiar years to produce extreme (R5) and severe (R4) radio blackouts during the period of investigation. Furthermore, the initial CMEs velocity related to higher proton intensity is significantly correlated with Dst than the lower proton intensity.

Keywords : Coronal mass ejection, geomagnetic storms, energetic particles, solar flare, ionospheric disturbances (radio blackouts)

PACS. Nos.: 96.60 ph, 90.30.Lr, 96.50.Vg, 90.qe, 94.20 Vv

1. Introduction

Many studies have been performed on the geoeffectiveness of CMEs. It has been reported that for geoeffectiveness of CMEs that they must arrive at Earth and have a southward component of their magnetic field [1]. CMEs originating from close to disk center (within 45 deg from the disk center) propagate roughly along the Sun-Earth line, so the front side halos are highly likely to arrive at Earth. Front halo limb CMEs (originating at longitudes beyond 45 deg and up to 90 deg) propagate at an angle to Sun-Earth line and only deliver a glancing blow to Earth's magnetosphere. CMEs ejected at angle exceeding 90 deg to the Sun-Earth line is unlikely to impact on Earth.

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Gopalswamy (2006) [2] has statistically analyzed that the product of CMEs speed (V_{CMEs}) and magnetic field strength, B at 1AU is the best set of parameters for the prediction of geomagnetic storms (GMSs) as compared to various combinations of V_{CMEs}, ICMEs speed (V_{MC}), B (magnetic field strength at 1AU) and southward component of interplanetary magnetic field, Bz have been considered in the past [3].

If the speed of the CMEs exceeds the local Alfven speed in the corona and interplanetary (IP) medium they can drive shocks which can accelerate electrons and ions generally known as Solar Energetic Particles (SEPs). Such CMEs are sometime referred to be SEPs effective. The close association between SEP events and CMEs was first pointed out by [4]. It is also well established that SEPs are accelerated by CMEs driven shocks [5] and protons are the dominant particle species in the SEP events [6]. However, Large Solar Energetic Particle (LSEP) events (defined as events with particle intensity exceeding 10 pfu (particle flux units) in the >10 Mev energy channel) have significant effect on the Earth and human enterprises. The protons in SEP events have different energy spectra, ranging from 10 KeV to > 10 Mev. Protons > 30 Mev penetrate space suits of astronauts and spacecraft skin to produce a significant radiation hazard; whereas, SEPs radiation of lower energies affect the electronic circuits, solar cells *etc.* SEP events ionize the polar mesosphere and stratosphere and affect the chemistry of upper atmosphere. After the largest events, ozone layer may be affected by a month or year.

The Ionosphere of Earth is a layer in the atmosphere, which consists of ionized gas called plasma and neutral particles. It affects radio propagation. During a solar flare the sunlit side of the Earth is hit by hard X-rays and ultraviolet radiation. They penetrate into the *D* layer and increase the ionization process and electron density. This will increase radio wave absorption especially in the upper Medium Frequency (MF) (300 KHz–3MHz) and lower High Frequency (HF) (3MHz–30MHz) ranges causing a radio blackout.

Geoimpact of CMEs generally falls into two categories : Geoeffectiveness and SEPs effectiveness. Geoeffective CMEs cause non-recurrent (also known as transient) GMSs. The SEP effective CMEs causes the gradual and long lasting SEP events. In the present investigation, an attempt has been made to study the geoeffectiveness of SEP effective CMEs.

2. Data and its analysis

All seventy five SEPs effective CMEs have been selected for the investigation of geospatial consequences during the period 1997-2005. These are classified into six groups according to proton intensity (I) as shown in Table 1. The six groups have been selected in such a way so that there is almost equal statistical distribution of number of events relating to the variation in the proton intensity. CMEs associated with SEP events are observed from the SOHO/LASCO CME catalog http://cdaw.gsfc.nasa.gov/

Table 1. Seventy five SEPs effective CME events have been classified into six groups as per variations in proton intensity, *I* in pfu.

Groups	Proton Intensity (pfu)	Number of Events
(a)	$I > 12000$	6
(b)	$1000 < I <= 12000$	9
(c)	$350 < I <= 1000$	10
(d)	$100 < I <= 350$	10
(e)	$30 < I <= 100$	17
(f)	$10 < I <= 30$	23

CME_list/ Velocity of CMEs are already listed in the CME catalog. SEP events of proton intensity $\geq$ 10 pfu in the 10 Mev channel measured by GOES instrument are identified from ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/Satellite_ENVIRONMENT/PARTICLES/p_events.lst. The source associated with SEP effective CMEs and their location have been examined by same website. Few of them are identified from Solar Geophysical Data (SGD). Geomagnetic storm associated with SEP effective CMEs are identified from Dst index data from World Data Center in Kyoto http://swdcwww.kugi.kyoto-u.ac.jp/dstdir/. Radio blackout has been selected according to NOAA Space Weather Scales (http://www.swpc.noaa.gov/NOAAscales/).

3. Results and discussion

The GMSs associated with SEP effective CMEs have been measured after the peak SEP flux appeared and with the minimum Dst value occurred same day or next day before first half of day. The scatter plots of the proton intensity and Dst have been drawn in the Figure 1(a, b) for different groups. When the higher order dependency of

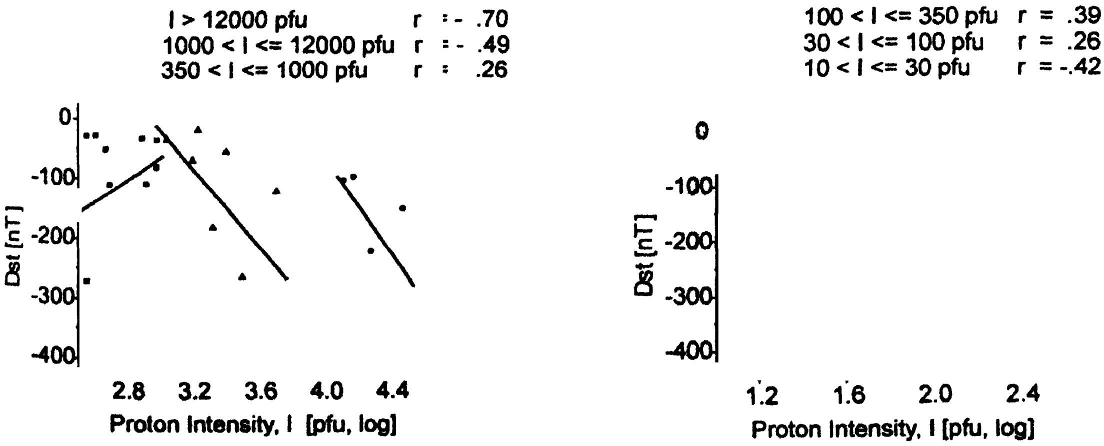


Figure 1. The scatter plot of Proton Intensity, *I* (pfu) and Dst (nT) for different groups have been plotted and best fit lines drawn. The correlation coefficients *r* between Dst and *I* for different groups are presented.

the parameters is considered and plotted for different groups of proton intensity and Dst, it is observed that correlation coefficient between these parameters is nonsignificant. Therefore, the linear relationship between these parameters has been considered for the analysis. Further, the correlation coefficients between Dst and different groups of proton intensity have been evaluated and as it is apparent from the values given in Figure 1(a, b) that there is better anti-correlationship between proton intensity, *I* > 12000 pfu and Dst. Thus, it is evident from here that as the proton intensity, *I* increase beyond 12000 pfu it leads to more depression in Dst value. This result is in agreement with [7]. It may further be inferred from here that when the SEP intensity increases above 12000 pfu, there is more probability of the particle to enter into the Earth's magnetosphere during the reconnection process between southward interplanetary magnetic field and northward geomagnetic field. Thus, they energize electrons and ions present in the geomagnetosphere; and therefore, they drift in opposite direction resulting in the ring current around the Earth. The magnetic field associated with the ring current essentially reduces the geomagnetic field as a result geomagnetic storm occurs. Furthermore, by looking the values of correlation coefficients, for different groups as given in Figure 1(a, b) as well, *i.e.*, no doubt the values of *r* for different groups are smaller; however, they are not insignificant; therefore, it is evident that lower proton intensity may also affect the ionospheric conditions. Marchese *et al*, [8] also observed that there is better correlation for SEP flux and ionospheric disturbances in quiet geomagnetic conditions. Finally, it is derived from here that SEPs intensity is also important factor, which affect the ionospheric condition leading to cause GMSs.

The scatter plots of the flare size in term of X-ray peak flux (w/m^2) and proton intensity have been drawn for different groups of proton intensity, *I* in the Figure 2(a,b).

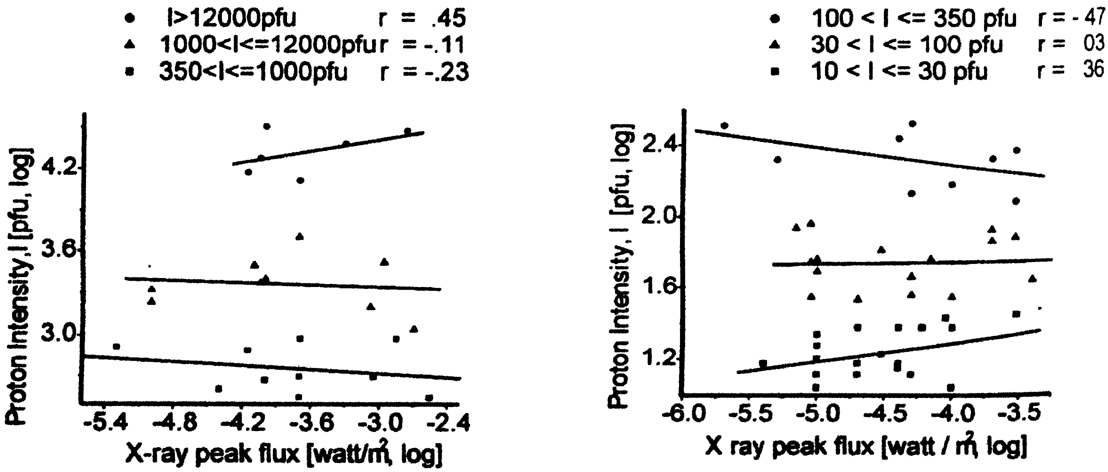


Figure 2. The scatter plots of flare size in terms of X-ray peak flux values of flare and Proton Intensity, *I* for different groups have been plotted and the best fit lines have been drawn . The correlation coefficient in the terms of X-ray peak flux is presented.

The correlation coefficient between these parameters has been evaluated and shown in Figure 2(a, b). It is quite apparent from here that there is no definite trend in the variation in these two parameters. Further, the correlation coefficient being not very significant therefore it is concluded that the flare in terms of X-ray peak flux is poorly correlated with the proton intensity, which is in agreement with Gopalswamy *et al* [9]. Actually the size of a soft X-ray flare signifies intensity soft X-ray emission from the flare plasma. The flare plasma is supposed to be the hot post eruption loops containing plasma evaporated from chromosphere. Higher flare size therefore implies a higher density of heated plasma over a large volume (*i.e.* higher emission measure) [10]. No doubt CMEs are associated with both big flare and small flare size, it does not imply that they always accelerate the electrons and ions and produce large SEPs intensity.

The scatter plots of the flare size and Dst have been shown in Figure 3(a, b) for different groups. The best fit line is drawn and the value of correlation coefficient is presented in the Figure 3(a, b). The overall observation suggests that there is no

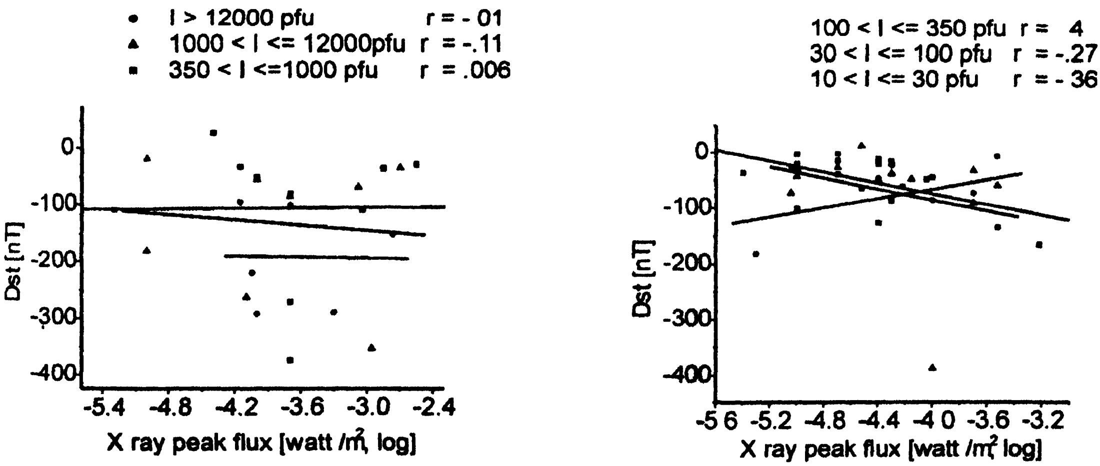


Figure 3. Scatter plots of flare size in terms of X-ray peak flux and Dst for different groups and the best fit lines have been drawn. The correlation coefficients between two parameters have been evaluated and presented.

significant correlation between the two parameters. Thus, it is concluded that GMSs do not depend on the flare size in terms of X-ray peak flux. It is in agreement with Gopalswamy *et al* [1] who have also observed that the difference in the flare sizes among geoeffective and non-geoeffective halos is not significant. Furthermore, the radio blackouts impact on Earth have been interpreted in terms of X-ray flare size. The distribution of occurrence of radio blackouts have been plotted histographically in Figure 4 for the period 1997-2005. It is inferred from Figure 4 that in 2001 and 2002 maximum number of overall radio blackouts have occurred. The strongest flare recorded during the period 1997 to 2005 is rated at X 28 on 4 November 2003. This is a R5 (Extreme)

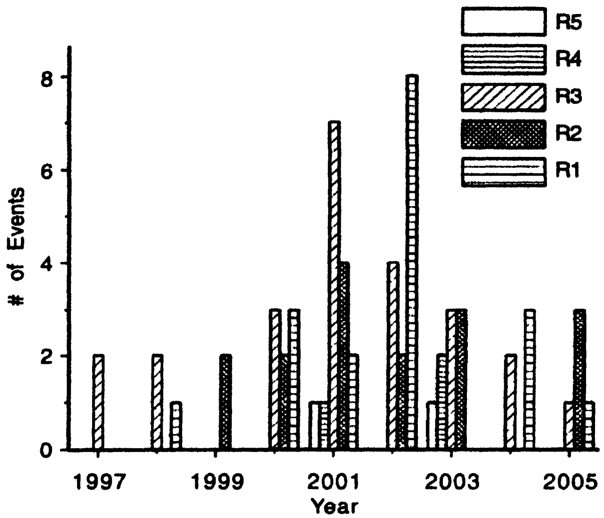


Figure 4. The distribution of radio blackouts associated with SEP effective CMEs during the period 1997-2005

radio blackout occurred said (SEC forecaster Bill Murtagh). The satellite remained in operational for 11 minutes duration; whereas, the second strongest flare recorded on 2 April 2001 rated X 20. It is observable that three severe (R4) radio blackout has occurred on 15 April 2001 and 28, 29 October 2003. Maximum numbers of strong (R3) and Minor (R1) radio blackouts have been observed in 2001 and 2002 respectively. Radio blackouts influence the navigation system, low frequency navigation signal used by maritime and general aviation systems experience outage on the Sun-lit side of Earth causing loss in the positioning on the Sun side of Earth, which may spread into nigthtside as well. The effect has also been seen in the high frequency radio communication, leading to interruption in the radio contact on sunlit side. However, duration of impact of the events on these radio blackouts at the Earth is different. According to NOAA Space Weather scale R5 (Extreme) ended number of hours; whereas, R1 *i.e.* (minor) ended few seconds.

The correlation coefficient between Proton Intensity (I) and Dst is of large practical significance. From Figure 1(a, b), it is observed that high proton intensity is responsible for producing GMSs and risk of high radiation dose to human and equipment on board in space satellites; whereas, from Figure 4 it is observed that lower proton intensity is responsible for radio blackouts *e.g.* on 28 November 2003, R5 (extreme) radio blackout is recorded (I = 353 pfu). Lower proton intensity ionizes the upper atmosphere, affecting the radio transmission.

The scatter plots of Dst *versus* longitude of source region producing SEPs effective CMEs from the disk center have been presented in the Figure 5 for different groups. It is observed that SEPs effective CMEs originate close to center disk producing intense GMSs (Dst < = −100 nT); whereas, events have occurred beyond 45

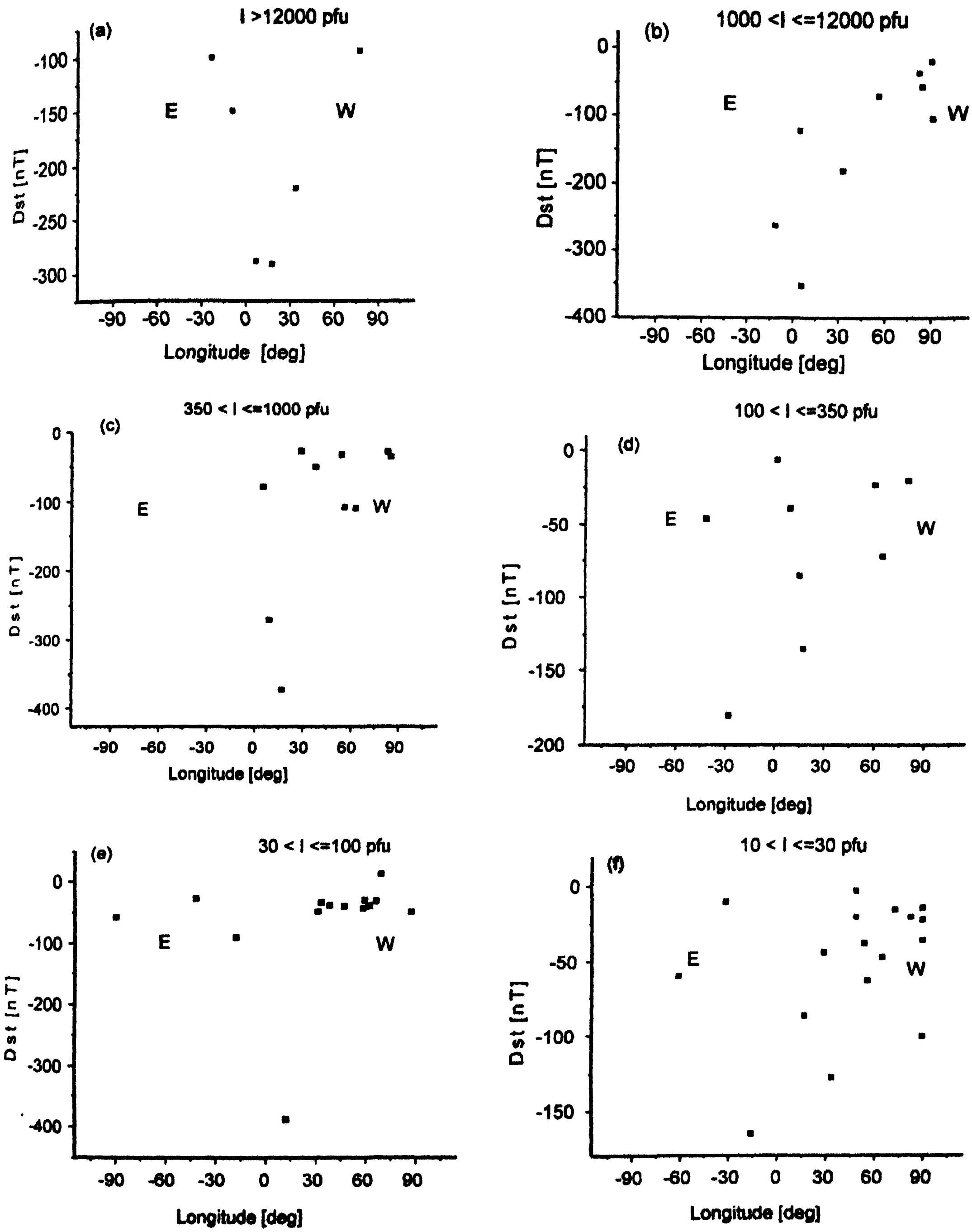
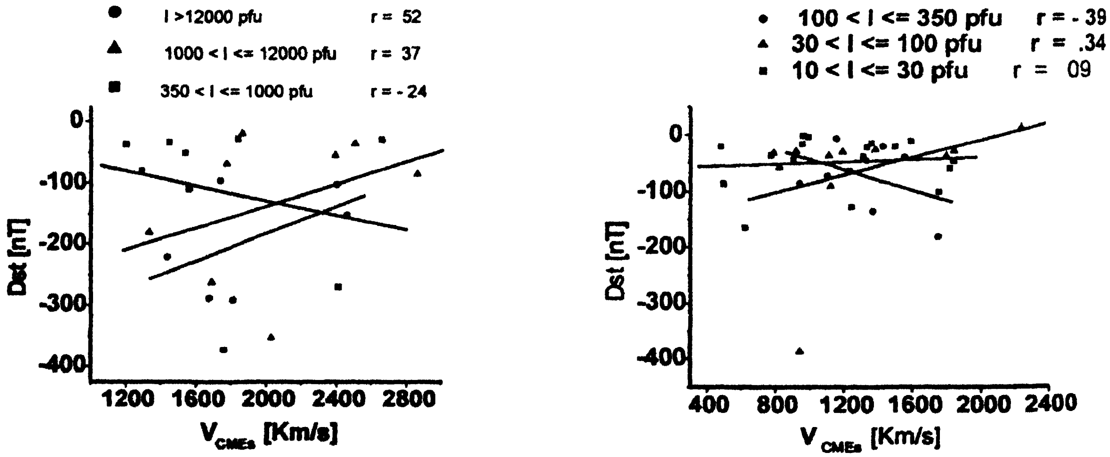


Figure 5. Scatter plot of Longitudes (deg) of source region producing SEP effective CMEs from disk center and Dst for different groups.

deg longitude from disc center are generally associated with moderate GMSs (–50 nT < Dst < = 100 nT). Most of geoeffective CMEs have occurred in western hemisphere.

It is in better agreement with the Gopalswamy *et al* [1] observations for halo CMEs It is also noticed that generally CMEs associated with high intensity SEPs originate close to disk center, whereas, lower intensity SEPs occur beyond 45 deg longitudes from the center disk. Figure 1(a, b) shows that there is no significant correlation between proton Intensity and Dst in case of lower SEP intensity (<100 pfu). Somehow it is observed that few events of lower SEP intensity are also responsible for causing GMSs. In such cases, the SEP effective CMEs should have occurred within 45 deg from the center of disk. It may be concluded from here that source location and the direction of SEP effective CMEs are important factors to decide the occurrence of GMSs.

The scatter plots of CMEs initial velocity and Dst have been shown in the Figure 6 (a, b) for different groups and the best-fit line has been drawn and correlation coefficient values for different groups are presented. It is observable from Figure 6 (a b) that two parameters are better correlated for the proton intensity I > 12000 pfu, whereas, the value of correlation coefficient for other groups is not that significant In case of SEPs effective CMEs initial velocity related with only higher proton intensity (*i.e.* I > 12000 pfu) play an important role for prediction of GMSs than the other groups; whereas, Gopalswamy *et al* [1] observed that the velocity of halo CMEs is the most important parameter in predicting the GMSs of halo CMEs. It is also observed that CMEs emitted with initial velocity greater than 1200 km/s are more responsible to produce high proton intensity. However, CMEs whose velocity is nearly equal to solar wind velocity, produce lower intensity SEPs.



Figrue 6. Scatter plots of CMEs initial velocity and Dst for different groups are shown and best fit drawn. The correlation coefficient is presented.

4. Conclusions

The following conclusions have been drawn on the basis of the present investigations

(1) Higher Proton Intensity (*i.e.* > 12000 pfu) is observed to be more geoeffective than the lower proton intensity.

(2) The flare size in terms of X-ray peak flux is not significantly correlated with the proton intensity of SEPs effective CMEs to cause GMSs.

(3) It is found that 2001 and 2003 are most peculiar year to produce extreme (R5) and severe (R4) radio blackouts during the period of the investigation.

(4) Source location is an important parameter for deciding on the nature of GMSs.

(5) Initial velocity of CMEs related to of higher proton intensity, *I* > 12000 pfu is better correlated with Dst than the lower proton intensity.

Acknowledgment

The authors are indebted to various experimental groups for providing the valuable data and in particular to Prof. N Gopalswamy for providing valuable information related to CMEs through Internet.

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